AD-A052 704   ROME AIR DEVELOPMENT CENTER HANSCOM AFB MASS DEPUTY--ETC F/G 20/1
                DIRECT SAW FREQUENCY SYNTHESIZER, (U)
                MAR 78   A J BUDREAU, P H CARR
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ETR-78-0050	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DIRECT SAW FREQUENCY SYNTHESIZER		5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Alan J. Budreau Paul H. Carr		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Deputy for Electronic Technology (RADC/EEA) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 64754F 63480002
11. CONTROLLING OFFICE NAME AND ADDRESS Deputy for Electronic Technology (RADC/EEA) Hanscom AFB Massachusetts 01731		12. REPORT DATE 28 Mar 78
		13. NUMBER OF PAGES 3
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Reprinted from 1977 Ultrasonics Symposium Proceedings, IEEE Cat. # 77CH1264-1SU, pp 511-513, October 1977.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Surface Acoustic Waves
Frequency Synthesizer
SAW Filters
SAW Comb Gen.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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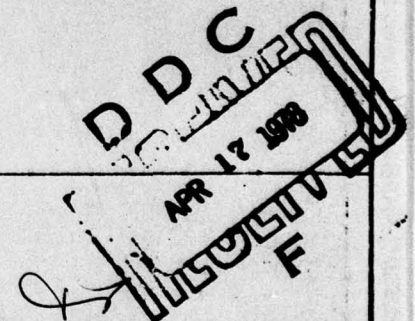
DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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A frequency synthesizer utilizing three elementary direct synthesizers to achieve fast frequency hopping among 219 tones is described. The elementary synthesizers used for the two 9-channel sets of tones consist of a comb generator followed by a surface acoustic wave (SAW) filterbank and a high speed 1 x 9 switch. Although this comb generator plus filterbank synthesizer is limited to cases in which the required frequencies are evenly spaced, this in fact does not prove to be very restrictive. The scheme is conceptually simple, and has signifigant advantages which are enumerated. Comparison is made with the mixed chirp synthesizer.

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DIRECT SAW FREQUENCY SYNTHESIZER

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ABSTRACT. A frequency synthesizer utilizing three elementary direct synthesizers to achieve fast frequency hopping among 219 tones is described. The elementary synthesizers used for the two 9-channel sets of tones consist of a comb generator followed by a surface acoustic wave (SAW) filterbank and a high speed 1 x 9 switch. Although this comb generator plus filterbank synthesizer is limited to cases in which the required frequencies are evenly spaced, this in fact does not prove to be very restrictive. The scheme is conceptually simple, and has significant advantages which are enumerated. Comparison is made with the mixed chirp synthesizer.

Introduction

The widespread requirements for frequency synthesizers for many types of electronics have led to the development of many competing designs. Phase locked loop oscillators, direct synthesis, and digital synthesis are the approaches generally used. Each of these can benefit from the use of some SAW components. The approach discussed here is direct synthesis with SAW components for size and cost reduction. To achieve 219 frequencies with only 21 tones required internally, a dual mixing scheme was chosen. A powerful alternative technique for frequency synthesis which has gained much attention has been the mixing of two linear chirps. The relative merits of each approach must be considered in connection with a particular application. As will be discussed later, requirements for frequency accuracy and stability and spurious levels precluded the use of the mixed chirp approach for this particular application.

Direct Frequency Synthesizer

A block diagram of the proposed synthesizer is presented in Fig. 1. In this design, a requirement for 219 tones required a more efficient design, in terms of tones per filter, than would have been achieved with a basic synthesizer of 219 tones. Furthermore, such an approach would have presented severe problems with the close relative spacing of the tones. By mixing together two sets of 9 tones and one set of 3 tones, we achieve capability of $9 \times 9 \times 3 = 243$ tones. This requires 18 SAW filters plus the 3 other frequency sources. In the particular application, we only make use of 219 of these. It should be noted that in a maximally efficient design, it would be possible to choose 7 tones which could be used 3 times, to yield $7^3 = 343$ tones with only 7 filters.

This synthesizer consists of four blocks. We will consider first the source package. The one MHz clock provides the reference to all five phase-locked-loop-oscillators (PLLOs) of the source package. PLLOs combined with triplers are an efficient way to achieve the high multiplication ratios for controlling the 333 MHz and 414 MHz mode-locked SAW oscillators (MLSOs).[1,2] Similarly, the very high and nonintegral ratios for the 1984 MHz, 1985 MHz, and 1986 MHz tones are obtained with the remaining three PLLOs, followed by multiplication by 20. The use of these PLLOs, along with the presence of a choice of 3 tones at the second mixer, plus the use of the doubler, represent the significant changes from the synthesizer reported previously.[3-5] A high-speed 3 x 1 switch allows rapid frequency hopping among the 1984-1986 MHz tones. The upper two outputs of the source package are comb spectra, as in Fig 2. We had originally planned to use conventional solid-state electronics for the entire source package. However, the MLSO approach has proved so attractive in reducing size, weight, cost, and power consumption that we have adapted it as our technique of choice.

The SAW and switch package is the "heart" of the direct frequency synthesizer. Each comb spectrum is multiplexed to a SAW filterbank fabricated on one to three chips. Each of the filterbanks has 9 simultaneous CW outputs, each of which is connected to the corresponding tap on a 1 x 9 high-speed switch. The output of each is a single fast-frequency hopped tone, which is then amplified. The lower output is doubled and filtered (the doubler package is the unlabeled small block), then fed to the first mixer. The difference tone, in the 378-615 MHz frequency range, is filtered and combined, in the second mixer, with the 1984-1986 MHz tone. The
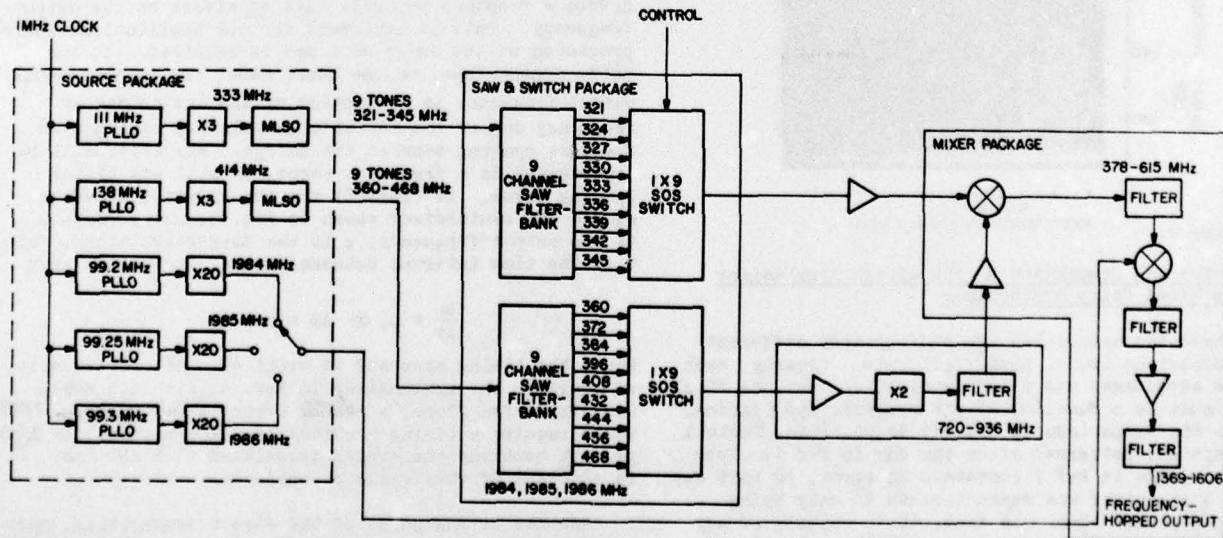

Figure 1   SAW FAST FREQUENCY SYNTHESIZER

difference signal out of the latter mixer, after appropriate filtering and amplifying with limiting, becomes the frequency-hopped output covering the 1369-1606 MHz frequency range. Choice of the levels, mixers, and filters is optimized[5] to keep the spurious signals the required 63 dB below the output level. Design of the SAW filters, themselves,[6] is particularly critical in obtaining the required performance. A combination of a withdrawal weighted and an apodized transducer was used for each filter, with double electrodes used throughout. The original mixer synthesizer design[5] had called for the higher set of 9 tones to be generated directly in the required 720-936 MHz band, but the design and fabrication of such SAW filters to meet the required specifications could not be quickly done. Reducing this band to one-half the frequency and adding the doubler package allowed the use of double electrodes and also allowed similar design techniques to be used for all of the SAW filters.

Experimental Results

A 321 MHz filter channel, with an insertion loss of approximately 16 dB, was completed as a test device. This channel was connected to the output of a prototype SAW comb generator developed by United Technologies Research Center.[1,2] The output of the comb generator, centered at 333 MHz, with 3.0 MHz signal spacing, as well as the 321 MHz output of the SAW filter, is shown in Fig. 2. The spurious level is below the maximum allowed -63 dBc level. Additional details may also be in Ref 6.
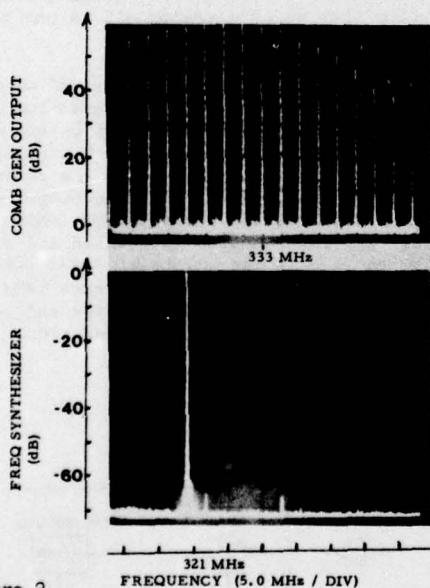
Figure 2.

Discussion and Comparison of the Direct Synthesizer and the Mixed Chirp Synthesizer

These two approaches are sufficiently different that comparison is, at best, difficult. Clearly, each has its advantages and disadvantages, so that the final choice must be a function of the specific application. To make the comparison as clearly as possible, Table 1 was prepared, patterned after the one in Ref 7. Note that the table in Ref 7 contained an error, in that our direct synthesizer was characterized as only being capable of short hops. In fact, it is capable of any length tone and usually is tested while producing CW. Figure 3 shows the two elementary synthesizers being compared. Advantages common to both these synthesizers are very rapid switching times (few nanoseconds),

compactness, and relative low cost and power consumption.

The direct SAW synthesizer, since it has all its tones available as CW, can yield a continuum of duration of tone from very short pulses (a few cycles) to CW. Note that the elementary chirp synthesizer inherently operates in an impulse mode, and can be used for long pulses or CW only at the expense of duplicating the lower part of Fig. 3 to allow the signal to be alternately produced by two channels.
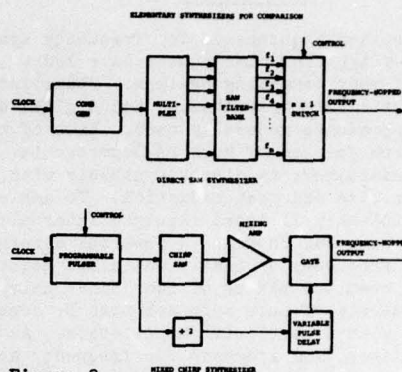
Figure 3

For the same reason, the direct synthesizer can be used either to yield n simultaneous tones, where n is the number of channels, or else for the maximum possible switching speed, limited only by the speed of the switch itself. Note that in a mixer direct synthesizer, as shown in Fig. 1, the CW signals present at the center of the figure can be multiplexed q-fold and the right-hand side of the figure duplicated q times to yield q simultaneous independent output signals. Since most of the cost, bulk, and power consumption are represented in the source package, this is an efficient route.

A major advantage of the direct synthesizer is that the output tones are ultimately derived from the input clock, so that their frequency accuracy also is derived from that clock. Note that it does not, for small increments in transducer dimensions, change with the SAW, i.e. fabrication or temperature-induced SAW frequency errors will degrade the output level or the spurious response but will have no effect on the output frequency. This is important for our application, where precision of the order of 1 ppm is required. In the chirp synthesizer, on the other hand, the instantaneous output frequency is a function of the instantaneous frequency out of the SAW at that point in time and of the time spacing between the chirps. Any error will be represented in a frequency error, as will any timing spacing error. If (ref. 8) for the simple difference single SAW synthesizer shown in Fig. 3, $\omega = \mu\tau$ where ω is the output frequency, μ is the dispersive slope, and τ is the time interval between pulses, it follows that

$$\frac{\partial\omega}{\partial\tau} = \mu, \text{ or } \Delta\omega = \mu\Delta\tau$$

thus, the timing accuracy is critical. If, for example, we consider the synthesizer in Ref. 8, with a 5 MHz/μ sec dispersive slope, a ~~timing~~ error of ~~0.1 nanosec~~ 1000 Hz would require a timing accuracy of 0.~~202~~ nanosec, or ~~200~~ ps, not counting the errors associated with the SAW. It is doubtful if this could be achieved.

Another strong point of the direct synthesizer, and one essential for our application, is its capability for achieving over 60 dB spectral purity, as shown in Fig. 2. Reference 8 indicated only about 24 dB for a mixed

Table 1. Comparison of Elementary Synthesizers

Synthesizer	Hop Duration	#Simult. Tones	Freq. Precision	Spectral Purity	S/N	Bandwidth	# of Freq.
Direct SAW	Any	n	As good as clock	> 60 dB	$> 100 \frac{dB}{Hz}$	That of Filterbank	n (n^m if m stages used)
Mixing Chirps	Short (long requires 2nd channel)	1	Limited by timing accuracy and SAW	~ 40 dB (RAC)	$> \frac{100}{TB} \frac{dB}{Hz}$	μT	continuum

chirp, and it is estimated that RAC filters can improve this to around 40 dB.

In many applications, the signal-to-noise ratio is an important parameter. Figure 2, taken at a band-width of 3 kHz, is consistent with a S/N ratio of over 100 dB/Hz. We have not yet set up the special narrow band measurement techniques required to determine whether it satisfies our design specifications for a noise floor of -122 dB/Hz. In this approach, it is important to keep the source noise from the mixers and amplifiers minimal by not allowing the power levels to drop to the point where the signal is no longer at the required amplitude above the noise. However, some broadband noise is filtered out by the SAW filters. In the mixed chirp approach, there is a "processing loss" (i.e., the opposite of processing gain) effect due to splitting up the energy of a single impulse into a wideband continuous spectrum to produce the chirp. Thus the S/N ratio is degraded by the time-bandwidth product, TB.

The bandwidth of the direct synthesizer is that achievable by the comb generator and the filterbank. As practical limitations hold each of these to around 25%, wider percentage bandwidths require mixing. Depending on the design approach, the mixed chirp synthesizer has a maximum bandwidth equal to the bandwidth of the SAW or equal to one-half that value.

The number of frequencies achievable by the elementary direct synthesizer is n, the number of filters. However, as in our example, the mixing of m stages with n tones each, allows the synthesis of n^m frequencies. In the mixed chirp synthesizer, on the other hand, there are no discrete frequencies, but rather a continuum available by "sweeping" the pulse interval. This is an advantage in terms of flexibility, but, as we have seen, a disadvantage in terms of frequency accuracy. So, here the choice depends critically on the specifications to be met.

Conclusions

Thus, while both of these types of SAW frequency synthesizers have their advantages, the direct synthesizer approach is clearly superior where high spectral purity, frequency precision, signal/noise ratio, or a combination of these factors is essential.

Acknowledgement

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